HIGH VOLTAGE SURGE AND PARTIAL DISCHARGE TESTS TO EVALUATE EQUIPMENT COMPONENTS

William G. Dunbar
Boeing Aerospace Company
Seattle, Washington 98124

and

Daniel L. Schweickart
Air Force Wright Aeronautical Labs
Wright-Patterson AFB, Ohio

Abstract

Airborne power supplies and equipment which supply megawatts of power at tens of kilovolts require designs of minimum weight and volume which imply compact systems with high density packaging. This is especially a concern of high voltage electrical components. This paper describes high voltage tests, test parameters, and the test results for capacitors, cables, and magnetic devices. In addition, the value of dielectric withstanding voltage tests compared to surge tests and partial discharge tests is discussed.

Introduction

Standards for design and testing of terrestial power system components and equipment have evolved through an iteration process involving interactions between designers, manufacturers, quality controllers, and users. High power/high voltage airborne systems do not have this developmental process on which to base design standards. As a result, in 1978 preliminary specifications were written for all the electrical, mechanical, and environmental requirements and test parameters for such system components.[1] The tests and standards which apply for commercial equipment were used and referenced when applicable. A test plan was then designed to evaluate and verify the parameters listed in the specifications for commercially available high-voltage components typically used in airborne systems. This was done by writing detailed test procedures, obtaining representative test samples, and testing to the specified parameters. Following completion of the overall testing program, the aforementioned test and specification criteria documents will be updated to reflect the findings.

When lightweight, high density packaging is required for a specific component design, it becomes necessary to electrically stress the dielectric material or insulation much greater than normally encountered in terrestial commercial applications. Corona tests clearly indicate the possibility of lack of insulation integrity with respect to voids and bonded joints within the insulation. Surge tests tend to open, or, in some cases, explode the deficiencies in such a manner that a clear signature may be obtained. Partial discharge tests are non-destructive but also may not be informative. Surge tests may totally destroy a test sample if improperly conducted or if there are flaws in the dielectric system which may eventually lead to shortened life or early failure. Selecting and ranking the tests must be done with great care.

Test Articles

Nine test articles were selected for high voltage evaluation to verify the specifications. These test articles represent critical components of a high-voltage, high-power airborne system. Included were cable assemblies composed of the cables and connectors, generator coils, and capacitors. To make the evaluation tests more meaningful, the capacitors and cable assemblies were selected from production lots, rather than development hardware programs. Therefore, manufacturing processes could also be evaluated.

Tests

Each component was given preliminary tests to determine insulation resistance at 100 volts dc, and the capacitance using a standard ASTM capacitance bridge at low voltage. These measurements were made to deter mine the loading for the partial discharge test equipment and the surge test load impedance. Insulation resistance was measured prior to high-potential tests. The pass criterion was that each test article have an insulation resistance of at least 1000 megohms.

High-voltage tests included dielectric withstanding voltage, surge test, and partial discharge tests. Visual tests were made during testing and following each test to determine failure sites on the test articles. The samples were all tested to values exceeding the manufacturers' specified rated values by 60 to 100 percent. It was desired to determine the limits of the insulation system and the value of each specified high-voltage test, rather than to evaluate the specified quality of the component.

High-Voltage Tests

High-potential tests are designed to electrically stress high-voltage components and equipment, but with safety margins sufficient to protect the equipment from damage or malfunction.

High-potential tests were intended to detect insu lation flaws, discontinuities, aging cracks, and deteriorated or inferior insulation. A hole or crack in insulation, across which a high voltage will discharge repetitively, may ultimately allow a carbonized conductive path to form and cause the insulation system to fail. These paths may be detected by high-potential tests. The high-potential for partial discharge and dielectric withstanding voltage (DWV) should be applied for 60 seconds. Repeated application of the high-potential can reduce the life of the insulation. Whether significant reduction in dielectric life occurs depends on the number of tests, the insulation material, and the insulation thickness. Ten high-potential tests should not permanently damage the insulation.

The dielectric withstanding voltage was applied between mutually insulated elements of each test article. For commercial equipment the test voltage requirement is two times normal voltage plus 1000 volts. The DWV test voltage specified was up to, but not exceeding double the operating voltage. The DWV test was decreased for the following reasons:

- o The component or equipment can have an overall life of approximately 10 years but is required to operate only 1 percent to 2 percent of that time.
- o All components will be burned-in and the qualification units will be accelerated life tested.

Report Documentation Page					Form Approved OMB No. 0704-0188
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE **JUN 1981**		2. REPORT TYPE **N/A**			3. DATES COVERED -
4. TITLE AND SUBTITLE **High Voltage Surge And Partial Discharge Tests To Evaluate Equipment Components**					5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)					5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Boeing Aerospace Company Seattle, Washington 98124**					8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)					10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**					
13. SUPPLEMENTARY NOTES **See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.**					
14. ABSTRACT **Airborne power supplies and equipment which supply megawatts of power at tens of kilovolts require designs of minimum weight and volume which imply compact systems with high density packaging. This is especially a concern of high voltage electrical components. This paper describes high voltage tests, test parameters, and the test results for capacitors, cables, and magnetic devices. In addition, the value of dielectric withstanding voltage tests compared to surge tests and partial discharge tests is discussed.**					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Surge Tests

Surge tests are known as basic insulation level (BIL) tests for commercial equipment. These tests are required for components and equipment that will be used where lightning, electromagnetic pulses (EMP), or switching surges are expected. A surge test subjects the insulation to a voltage pulse having a rise time of 1.2 microseconds, and a 50-microsecond fall to one-half peak voltage. This is a slower rise time than an electromagnetic pulse which has a rise time as fast as 1 to 10 nanoseconds. Surge tests were conducted using the procedures outlined in IEEE Publication, Number 4, 1978.

It was specified that the test articles be surge tested with 5 to 10 positive impulses. For commercial equipment the peak voltage of the surge test is usually about 5 to 6 times the operating voltage. A value of 1.6 to 2.0 times the operating voltage is recommended for airborne equipment, since transients in these systems are generally limited to 150 percent of the operating voltage.

Partial Discharge Tests

Partial discharge (corona) tests are used to seek out insulating material flaws by detecting partial discharges which occur in laminations, cracks, and voids. Each test article was connected to the high voltage circuit of a partial discharge test facility and tested for partial discharges and/or corona. Capacitors were tested with dc voltages only. The following details applied to the tests.

- o. Magnitude of test voltage - 100 percent rated operating voltage (dc or ac, as applicable)
- o Duration of application of test voltage--partial discharges shall be measured for 60 seconds after the operating voltage is attained. Voltage shall be increased from 0 to operating test voltage at a rate of 500 volts per second. A waiting period of 2 minutes shall occur at full steady-state voltage before partial discharge counting commences.
- o Partial discharges for organic insulation shall not exceed more than one discharge per minute above 10 pc. Partial discharges greater than 1000 pc are unacceptable for organic-insulated components.

Findings

Low Voltage Tests

The low voltage tests were made following a visual inspection. Each test article surpassed the minimum specified insulation resistance of 1000 megohms. The capacitance of the cable assemblies, capacitors, and coils were all within 5 percent of the calculated or manufacturer's specified value.

Dielectric Withstanding Voltage

The test articles were subjected to dielectric withstanding voltage values based upon the manufacturer's recommendation for the component's rated operating voltage. Dielectric withstanding voltage measurements were taken in a step series sequence with 10 seconds hold at each of the lower voltage levels and one minute hold at the highest voltage. The first three steps were at rated voltage, 125 percent, and 150 percent rated voltage; the final step was taken at the full DWV voltage. The full DWV for capacitors and generator coils was 200 percent rated voltage and the full DWV for cables and cable assemblies was 160 percent rated voltage. All test articles passed the dielectric withstanding voltage test. The voltage was decreased at a rate of 10,000 volts per second following the one-minute hold at the rated DWV voltage. A visual inspection of the test articles revealed no indication of damage by arcing, heating, or tracking following the DWV test.

Surge Test

Several test articles failed to survive the 200 percent rated surge voltage test shown in Table 1. One cable assembly (A-4) and one capacitor (B-3) failed to pass a surge test at rated voltage. This indicated that the test article was either damaged by the DWV test, there were flaws in the insulation system which were not identified by the DWV test. Obviously, the surge test gave a better indication of insulation integrity than the DWV test on these components.

TABLE 1. SURGE TEST DATA

Test Article	Part Designation	Voltage, kV	Test Voltage, kV	Status
Cable	A-1	90	120	Fail
Cable Assembly	A-2	90	120	Fail
	A-3	60	75	Fail
	A-4	60	50	Fail
Capacitor	B-1	100	110	Pass
	B-1	100	165	Borderline Pass
Capacitor	B-2	100	119	Pass
			155	Damaged
Capacitor	B-3	80	51	Pass
			48 2nd test	Fail
Capacitor	C-1	15	14.5	Pass
Generator Coil Turn-To-Turn Insulation Thickness (Polyester-Glass)				
	12 mils D-1	2.8	8	Fail
	18 mils D-2	2.8	8	Pass
	24 mils D-3	2.8	11	Pass
	30 mils D-4	2.8	13	Fail

Some photographs of good insulation integrity and of breakdown are shown in Figures 1 and 2 for the alternator coils and Figures 3 and 4 for the cable assembly (A-3). The two photographs shown in Figures 1 and 3 are of signals produced by the surge tester operating into a matched line impedance indicating a good insulation system. The waveforms displayed in Figure 2 and 4 represent the same initial waveform terminated into a shorted or partially shorted circuit. The initiation time for the short circuit is calculated by determining the maximum voltage rise to the sudden fall before the oscillations occur.

The cable assembly A-2 was tested to 120 kV peak. Following the test, the test data waveform indicated an insulation breakdown. The cable was examined and a puncture was visible at the cable shield termination. The termination was dissected and the insulation flaw was found to be between the primary insulation and the shield extending into the primary insulation toward the inner conductor, Figure 5. In Figure 6, the delaminated insulation system is exposed. Shown is a crack and a very dark spot where the arcing occurred. The bright area indicates an unbonded section near the shield termination--an air filled void.

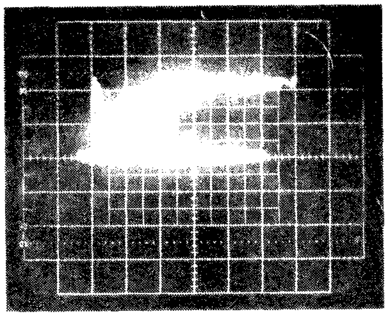

Figure 1: Generator Coil, D-2, Negative Surge; Vertical: 4kV/div; Horizontal: 500ns/div

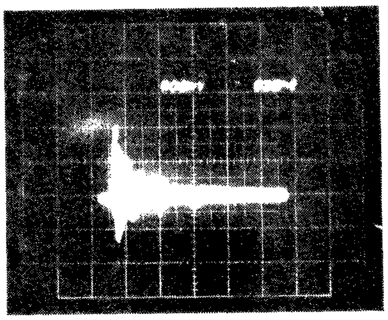

Figure 2: Generator Coil, D-1, Negative Surge Failure; Vertical: 2kV/div; Horizontal: 500ns/div

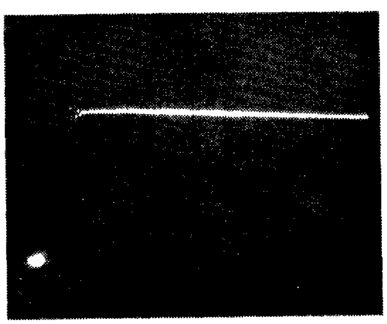

Figure 3: Cable Assembly, A-3, Positive Surge; Vertical: 10kV/div; Horizontal: 2μs/div

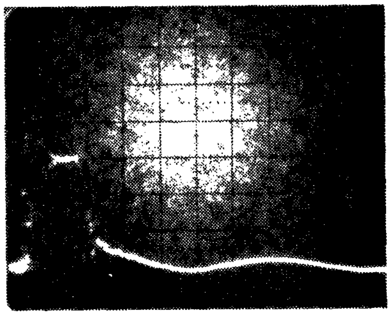

Figure 4: Cable Assembly, A-3, Positive Surge Failure; Vertical: 20kV/div; Horizontal: 2μs/div

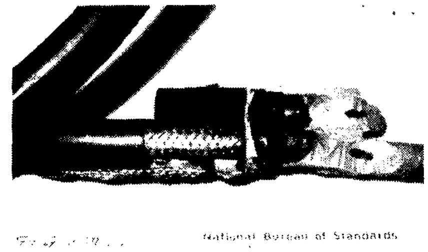

Figure 5: Cable Assembly, A-2, Post Surge Test Failure Analysis Showing Shield Bond Void

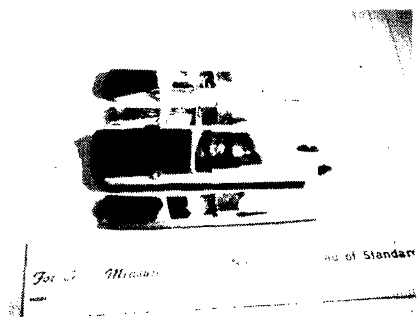

Figure 6: Cable Assembly, A-2, Showing Detail of Bond Failure

Partial Discharge Test

Each test article was subjected to a partial discharge. Test results for the components are shown in Table 2. The test data for these items were derived from the outputs of a corona test set which includes a Nuclear Data ND-60 pulse height analyzer. The counts per second recorded in Table 2 are the accumulated pulses recorded for all channels indicated.

The partial discharge test data indicated that the test articles were damaged by either the DWV or surge testing. This damage to the insulation resulted in very high partial discharge test signatures. This is an indication that more voids exist either by delamination, as is the case for the damaged cable assemblies, or that the liquid was forced from weak areas within the capacitor foils. All components that indicated surge test damage had higher than normal picocoulomb readings.

A capacitor (C-1) with no indication of surge test or DWV test damage had very low picocoulomb readings before and after the surge tests.

The generator coils are insulated with a polyester glass matrix with the edges of each coil exposed to atmospheric conditions. Therefore, partial discharges will be generated within the polyester glass matrix and in the air space across the coil edges. Partial discharges as high as 350 picocoulombs were recorded for two coil surfaces. These large readings, although undesirable, will not damage the insulation within the allowable equipment lifetime of approximately 100 hours. The ac partial discharge initiation and extention voltages are 2.9 and 2.7 kV, respectively.

TABLE 2. PARTIAL DISCHARGE TEST DATA FOLLOWING SURGE AND DWV

			Number of Partial Discharges/Second At Rated Voltage						
			Pulse Height - PC						
Test Article	Part Designation	Test Voltage	1-2	3-4	4-5	9-10	20-30	30-40	Status
Cable	A-1	75.3	Many	1.45	0.65	0.03	0.7	0.012	fail
Cable Assembly	A-2	Connector breakdown during surge test							fail
Cable Assembly	A-3	60.3	2.77	0.5	0	0	0	0	pass
Cable Assembly	A-4	50.3	3.4	1.5	0.02	0	0	0	pass
Capacitor	B-1	100.1	50	0.8	0.41	0.18	0.33	0.03	fail
Capacitor	B-2	99.7	0.5	0.215	0	0	0	0	pass
Capacitor	B-3	Breakdown occurred at 2.5 kV							fail
Capacitor	C-1								
Presurge		15	0.0	0	0	0	0	0	pass
Postsurge		15	0.016	0	0	0	0	0	pass

Conclusions

Based on the test articles evaluated in this program, the following conclusions are drawn:

- Nine high-voltage components were subjected to the insulation resistance, capacitance, dielectric withstanding voltage, surge, and partial discharge tests. It was found that the insulation resistance and capacitance test methods and parameters are acceptable. The partial discharge and dielectric withstanding voltage and surge test methods are acceptable but the test parameters for airborne components must be lower than that specified for heavier, larger volume commerical components of the same voltage and energy ratings.

- The dielectric withstanding voltage parameters should be reduced to 160 percent component rated voltage to adequately test the component yet not destroy its insulation integrity or reduce the insulation life.

- To prevent insulation system damage, the surge peak voltage should be limited to 200 percent component rated voltage. In addition, the surge test voltage wave shape must be revised to the acceptable limits imposed by the anticipated surges inherent in the design of the equipment.

- A new test sequence should be followed to verify insulation integrity following the high-voltage DWV and surge tests. The sequence should be:

  insulation resistance
  capacitance
  partial discharge
  dielectric withstanding voltage
  surge
  partial discharge

- Components passing the DWV and surge tests must pass the second partial discharge test with less than 20 percent increase in picocoulomb maximum partial discharge in a one-minute test period. Values exceeding 20 percent increase indicates permanent internal damage to the insulation.

- Partial discharge magnitudes for the polyester-glass insulated generator coils must be much higher than for shielded or contained components, such as cable assemblies and capacitors. Maximum picocoulomb values to 1000 pc are acceptable for the alternator polyester-glass matrix materials.

References

1. W. G. Dunbar, "High Voltage Specifications and Tests (Airborne Equipment)", AFAPL-TR-79-2024, Air Force Aeropropulsion Laboratory, W.P.A.F.B., Ohio, April 1979.

Acknowledgement

This work was sponsored by the U.S. Air Force Wright-Aeronautical Laboratories, Aeropropulsion Laboratory, Wright-Patterson Air Force Base, Ohio under contract F33615-79-C-2067, "High Voltage Testing."